

Comprehensive analysis of Heavy Metal Composition and Physico-Chemical Properties in Effluents from Sugar and Dairy Industries: Assessing Environmental Implications

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Abstract

Aim: This research is dedicated to examining the physical and chemical properties of effluents from the sugar and dairy industries post-treatment, as well as their heavy metal composition, and how these factors affect the environment.

Methodology: Total six samples collected and analyzed from the sugar mill and twelve samples from the dairy industry, all of which had undergone treatment. Standard methods (APHA and ICPOES) were employed to assess their physico-chemical characteristics and heavy metal content.

Results: With the exception of a few heavy metals, all parameters met the irrigation water quality standards set by Indian regulations. The evaluation index for heavy metals in the dairy industry effluent indicated a higher heavy metal content compared to that in the sugar industry effluent. The heavy metal contents in the sugar and dairy industry discharge water were respectively: Ni: Nil and 0.524 mg/L, Pb: Nil and 1.29 mg/L, Zn: 0.459 and 1.66 mg/L, Fe: 0.463 and 1.36 mg/L, Mn: 3.93 and 8.17 mg/L.

Interpretation: The results from the analysis of treated effluents from the sugar and dairy industries suggest that if these effluents are discharged into the environment without proper treatment, they could potentially cause adverse effects on both aquatic and terrestrial ecosystems. Consequently, this study strongly recommends the implementation of effective wastewater treatment methods, particularly for the removal of heavy metals. Considering that the volume of treated effluent generated by both industries is relatively low, there is an opportunity to utilize it by blending it with irrigation water for agricultural purposes. This practice not only helps in minimizing the environmental impact of contaminants but also serves as a sustainable approach to resource utilization.

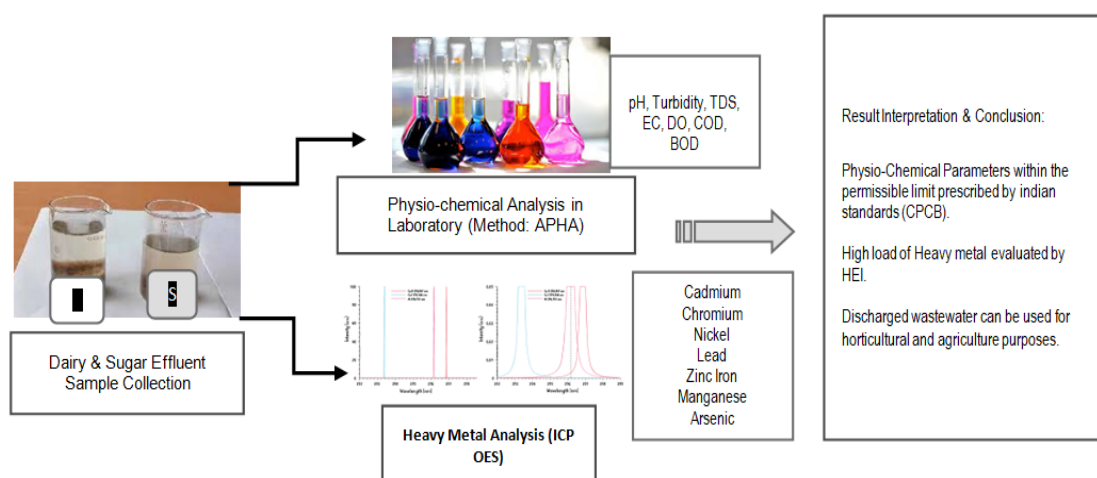


Fig 1: Graphical abstract representation

Keywords: Dairy industry, Environment. Heavy metals, Physico-chemical parameters, Sugar industry

1. Introduction

The twenty-first century is witnessing significant ecological challenges, with population growth, mechanization, agricultural practices, and development all contributing to a pressing issue: the availability and quality of water. This critical concern has arisen due to substantial alterations in global hydrological patterns caused by climate change and socioeconomic progress. These shifts have had severe repercussions on water resources and aquatic ecosystems [1,2]. Additionally, changes in rainfall patterns and alterations in water consumption and extraction are impacting the supply of both surface water and groundwater. It is anticipated that these trends will persist and become a primary driver of water shortages in numerous regions [3,4].

Water is the most essential and invaluable natural resource on our planet, serving as a critical necessity for various purposes, including household use, agriculture, and industrial processes. However, it's worth noting that less than 1% of Earth's water is pure and fresh, while around 2% comes from glacial meltwater, leaving approximately 97% of our water as highly saline [5].

Among various industries, the food production sector, particularly sugar and dairy industries, stands out as a significant source of wastewater. In India, dairy plants, on average, produce 6-10 liters of wastewater for every liter of milk they process [6]. These dairy facilities discharge substantial volumes of wastewater characterized by high concentrations of organic matter, along with significant quantities of casein, fat, lactose, salts, detergents, and sanitizers, among other components [7].

Within the realm of industries contributing to water pollution, sugar mills play a prominent role in contaminating both water sources and soil. While sugar industries significantly contribute to India's economic growth, the wastewater they release poses a substantial threat to terrestrial and aquatic ecosystems due to its high pollution levels. The discharged wastewater also alters the physical and chemical characteristics of the receiving water bodies, impacting the local flora and fauna. Consequently, the release of wastewater from sugar mills into the environment represents a serious health and economic risk to the exposed populations.

Many nations are grappling with the challenge of effectively managing their water resources, balancing the needs of the public, industry, agriculture, and the environment. To meet the growing demand for water, there is a growing interest in exploring alternative water sources such as desalinated water, marine water, and reclaimed water. Reclaimed water refers to treated wastewater that has had solids and contaminants removed, making it suitable for various beneficial purposes like agriculture, industrial processes, toilet flushing, and replenishing groundwater.

The demand for water is on the rise due to factors such as population growth, increasing urbanization, and the effects of climate change. According to a recent analysis by the United Nations (UN), the global population is projected to reach approximately 8.5 billion by 2030 and around 9.7 billion by 2050. This population surge, coupled with changing climatic conditions, is putting immense pressure on water resources and giving rise to various issues, including erratic river flows, dwindling water sources, and ecological deterioration [8,9,10].

Therefore, reclaimed water emerges as a viable alternative water source in regions facing high water demand. Reclaimed water is obtained from treated wastewater at wastewater treatment facilities, where it undergoes treatment to meet specific water quality standards with the intention of being used for a wide range of purposes (as illustrated in Figures 2 and 3). Consequently, reclaimed water offers significant advantages for non-potable applications such as irrigation in agriculture, urban sanitation, firefighting, construction, industrial processes, recreational activities, and environmental conservation efforts, including surface water and groundwater replenishment [11,12].

Industrial wastewater discharge is a significant contributor to both water pollution and disruptions in ecosystems. The environmental impacts of industrial discharges on aquaculture and agriculture are of particular concern. With these considerations in mind, this study was conducted to assess the physical and chemical properties of treated wastewater generated by the dairy and sugar industries, with the aim of determining its potential for reuse. This reuse could help alleviate the strain on freshwater resources and reduce environmental risks.

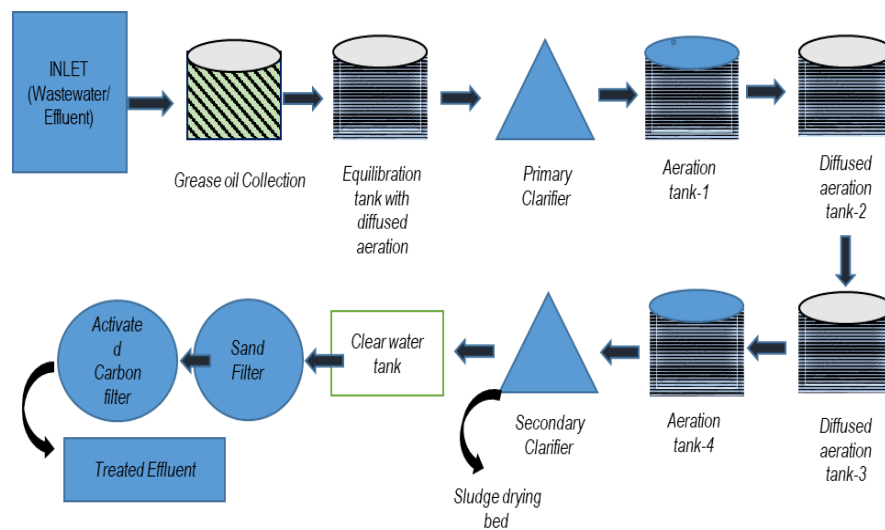


Fig 2: Process flow diagram; Industrial effluent treatment

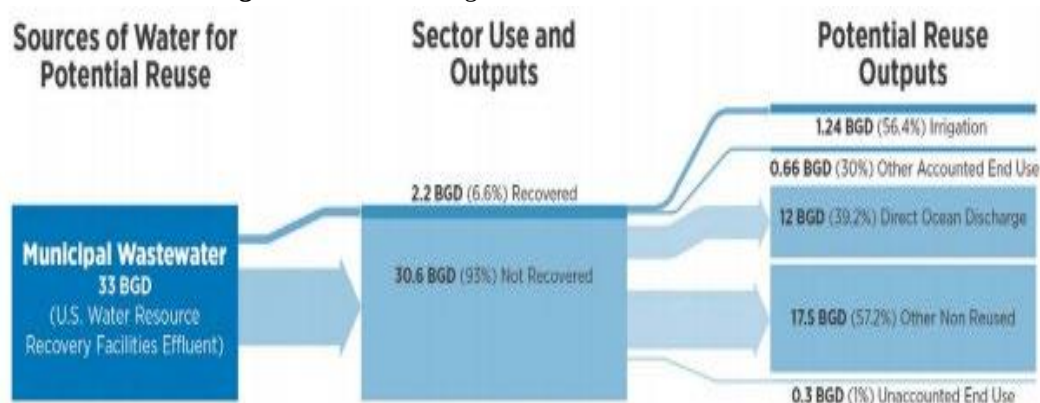


Fig 3: Potential reuse categories of municipal wastewater, [13].

2. Materials And Methods

Effluent samples were collected from the discharge points of a sugar mill and a dairy industry located in the Saharanpur district of Uttar Pradesh, India. This collection took place monthly from January to June for the sugar mill and from January to December for the dairy industry, as illustrated in Figures 4 and 5. The samples were carefully placed in labeled and clean plastic bottles and stored at a temperature below 5°C until they were utilized. Various physico-chemical parameters, including temperature, color, pH, turbidity, electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD), total dissolved solids (TDS), and chemical oxygen demand (COD), were examined according to the procedures outlined in the American Public Health Association (APHA) guidelines and Trivedi and Goel (1984) [14, 15, 16]. Heavy metal concentrations were determined using the standard ICP-OES method.

All reagents and chemicals used in the analysis were within their specified expiry dates and suitable for the intended purpose. Furthermore, all equipment and glassware used in the experiments were properly calibrated and deemed fit for use. As part of QC, all experiments performed on calibrated equipment and with positive and negative control sample at the time of test sample analysis.

The observed results obtained from these analyses are presented in Tables 1 and 2. It's important to note that observations and results were meticulously recorded in the laboratory at the time of the experiments, adhering to the principles of Good Laboratory Practices.

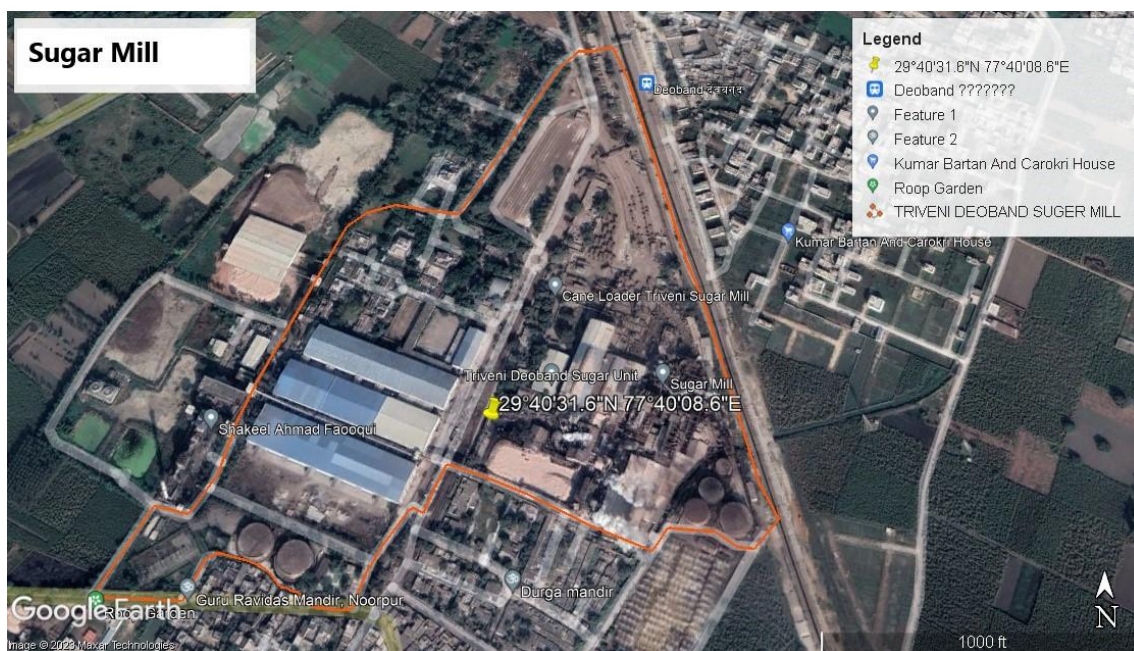


Fig 4: Industry Location Map: Sugar mill

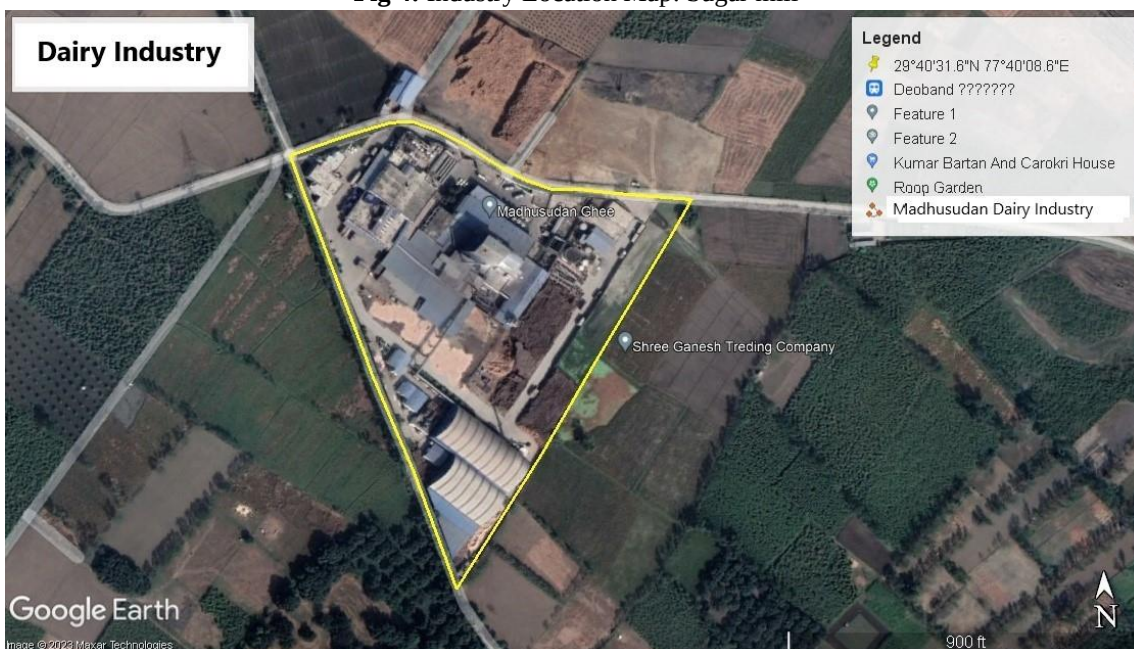


Fig 5: Industry Location Map: Dairy Industry

A total of six effluent samples were gathered monthly from a sugar industry between January and June 2022. Additionally, twelve samples were acquired from a dairy industry spanning from January 2022 to December 2022. The analysis focused on examining various physico-chemical parameters. Specifically, heavy metal analysis was exclusively conducted on the samples collected in May 2022. Effluent temperature was measured during sample collection, and all parameters except for heavy metals were analyzed within 24 hours of collection. Tables 1 and 2 contain the physico-chemical characteristics of the treated effluent, which were used to assess its quality. Corresponding regulatory standards for potential reuse are provided in these tables. The obtained results for physico-chemical parameters and heavy metals underwent statistical analysis, which included mean values, standard deviations and relative standard deviation (RSD), all performed using a computer system.

3. Results And Discussion

Statistical analysis of obtained results for Physico-chemical (Table-1& Table-2) and Heavy metals (Table-4) were analyzed by mean, standard deviations and coefficient of variation (CV) by Microsoft® Excel 2013.

Table 1: Physico-chemical Properties of Treated Effluent of Sugar Industries.

Parameters	Mean	SD	RSD	Result	CPCB-General Standards for Discharge-Inland Surface Water	FAO-1985 Water Quality for Agriculture	US EPA-2012, water quality criteria for irrigation
Temperature °C	27.73	6.78	24.46	27.7 ±6.78	NG	NG	NG
pH	7.57	0.47	6.15	7.6 ±0.47	5.5-9.0	6.5-8.4	6.5-8.5
Turbidity (NTU)	2.15	0.85	39.65	2.2 ±0.85	NG	NG	NG
TDS (mg/L)	888	170	19.17	888 ±170	NG	450-2000	NG
EC (µS/cm)	1259	267	21.20	1259 ±267	NG	700-3000	700-3000
DO (mg/L)	6.09	1.60	26.31	6.1 ±1.60	NG	NG	NG
BOD (mg/L)	13.21	1.48	11.22	13.2 ±1.48	30	NG	10
COD (mg/L)	46.67	6.63	14.21	46.7 ±6.63	250	NG	NG

Colour: Translucent

Table 2: Physico-chemical Properties of Treated Effluent of Dairy Industries.

Parameters	Mean	SD	RSD	Results	CPCB-General Standards for Discharge-Inland Surface Water	FAO-1985 Water Quality for Agriculture	US EPA-2012, water quality criteria for irrigation
Temperature °C	30.00	5.58	18.59	30.0 ±5.58	NG	NG	NG
pH	7.48	0.54	7.26	7.5 ±0.54	5.5-9.0	6.5-8.4	6.5-8.5
Turbidity (NTU)	89.23	4.51	5.06	89.2 ±5.06	NG	NG	NG
TDS (mg/L)	832	222	26.71	832 ±222	NG	450-2000	NG
EC (µS/cm)	1178	244	20.69	1178 ±244	NG	700-3000	700-3000
DO (mg/L)	6.40	1.30	20.33	6.4 ±1.30	NG	NG	NG
BOD (mg/L)	13.46	2.27	16.86	13.5 ±2.27	30	NG	10
COD (mg/L)	51.69	9.68	18.73	51.7 ±9.68	250	NG	NG

Colour: Creamish white

4.1 pH

The pH scale, introduced in 1923 by Danish biochemist Søren Peter Lauritz Sørensen (1868-1969), is a measure of the concentration of hydrogen ions in a substance. It is commonly used to indicate the acidity or alkalinity of a solution on a scale ranging from 0 to 14.

The pH levels of both treated effluents, namely Sugar and Dairy, have displayed remarkable stability, with no significant variations observed across samples collected in different months. All samples consistently exhibited a basic pH. The average pH for Sugar and Dairy was recorded at 7.57 and 7.48, respectively, falling within the acceptable range specified by the CPCB standards (5.5 to 9.0) [17,18,19,20]. These pH values are suitable for discharging into surface water and for irrigation. Notably, the pH of the discharge water from both locations remained within the prescribed discharge standards. It's essential to maintain a pH within the range of 6 to 9, as values outside this range can disrupt biological processes, hindering the anaerobic digestion of organic materials. A pH above 9 can lead to the precipitation of calcium carbonate, resulting in a milky appearance in the water. Lower pH levels may release toxic metals trapped in sediment. Thus, pH plays a critical role in ensuring the effective treatment of water supplies, as a pH above 8.3 can interfere with the decontamination process for drinking water.

4.2 EC

Conductivity serves as the measure of a solution's ability to carry an electric current. It's important to note that resistance and conductivity have an inverse relationship. Since most of the electrolytes in water exist in ionic forms, making them capable of conducting electricity, conductivity becomes a reliable and swift indicator of the total dissolved solids (TDS) present. Essentially, electrical conductivity quantifies water's electrical conductivity capacity, offering an estimation of TDS or electrolyte concentration. Generally, as the amount of dissolved solids increases, electrical conductivity tends to rise, typically by a factor of 1.0 to 1.5 times. This measurement is expressed in micro-Siemens per centimeter ($\mu\text{S}/\text{cm}$). It's worth mentioning that electrical conductivity is influenced by temperature and mineral ionization. For industrial effluent, the electrical conductivity falls within the range of 800 to 1500 $\mu\text{S}/\text{cm}$, but the relative standard deviation (RSD) exceeds 20% for both cases. However, when comparing the overall electrical conductivity results for both industrial effluents to the Indian standard (2250 $\mu\text{S}/\text{cm}$), they meet the requirements for irrigation purposes. Salinity, a critical aspect of agricultural water quality, is often denoted by electrical conductivity (EC). High salinity levels can be detrimental to crop nutrient absorption. The guidelines established by the Food and Agriculture Organization (FAO) in 1985, as revised by Ayers and Westcott [21], are internationally recognized and based on salinity. They provide insight into the impact of salinity on crop development. Specifically, when water EC remains below 700 $\mu\text{S}/\text{cm}$, it does not exhibit any adverse effects on crop development. However, if it exceeds 3000 $\mu\text{S}/\text{cm}$, it can cause severe damage to crops.

4.3 Total dissolved solid (TDS)

The term "TDS of wastewater" refers to the concentration of total dissolved solids in the water. Human activities, such as farming and industrial processes, can lead to an increase in the levels of TDS in water sources. An excess of TDS in a water body can be harmful to aquatic organisms. The TDS content in the effluent from the sugar industry was found to be higher than that of the dairy industry. Specifically, the average TDS value for the sugar industry effluent was 888 (mg/L), which is greater than the average TDS value of 832 (mg/L) for the dairy industry effluent. The relative standard deviations (RSD) for TDS in the sugar and dairy industry effluents were 19.17% and 26.71%, respectively. This indicates a significant variation in TDS levels at different times during the study period. In summary, the overall TDS levels in both the sugar and dairy industry effluents were in compliance with the Indian standard "IS 2296:1992- Irrigation-E," which specifies a limit of 2100 (mg/L) for irrigation purposes [22]. Therefore, both types of industry effluents are suitable for use in irrigation.

4.4 TDS/EC Ratio

The water quality parameters EC and TDS serve as indicators for assessing the salinity level of water. Among these parameters, the TDS value plays a more straightforward role in describing water quality compared to the EC value. Numerous research studies have been conducted to establish the relationship between EC and TDS. The findings of these investigations indicate that the TDS/EC ratio falls within an acceptable range, specifically between 0.5 and 0.75 as presented in Table-3. Consequently, the TDS/EC ratio obtained from these

studies is deemed suitable for water applications in irrigation. Anna F. Rusydi provided a comprehensive explanation of the TDS/EC ratio in 2018 [23].

Table 3: TDS/EC Ratio of Dairy and Sugar Industry

Sr. No.	Parameters	Mean Value	
		Dairy Industry	Sugar Industry
1	TDS (mg/L)	832	888
2	EC (μ S/cm)	1178	1259
3	TDS/EC Ratio	0.707	0.705

4.5 Dissolved Oxygen (DO)

According to the US Environmental Protection Agency (EPA), dissolved oxygen refers to the oxygen available in water. Flowing water typically contains a higher amount of oxygen compared to stagnant water sources. Aquatic organisms depend on dissolved oxygen for their survival. When excess organic matter, such as algal blooms, decomposes through the action of microorganisms, it consumes the dissolved oxygen in the water, leading to conditions of hypoxia (low oxygen levels) or anoxia (complete lack of oxygen) in the water. Oxygen deficiency often occurs at the bottom of bodies of water and can disrupt the life of organisms residing there. Dissolved oxygen levels below 3 mg/L are a cause for concern, and levels below 1 mg/L are considered hypoxic, posing a threat to aquatic life. The overall levels of dissolved oxygen in effluents from the sugar and dairy industries are found to be similar. However, the average dissolved oxygen values for sugar mills and dairy industry effluents are 6.1 (mg/L) and 6.4 (mg/L), respectively. The relative standard deviation (RSD) for dissolved oxygen in both sugar and dairy industry effluents exceeds 20%, indicating significant variation in monthly data for dissolved oxygen. Overall, the dissolved oxygen results meet the standards outlined in the Indian standard "IS 2296:1992- Aquaculture-D," which requires 4 (mg/L) or more of dissolved oxygen for both industry effluents. Therefore, these effluents are suitable for use in irrigation as well as aquaculture and fisheries.

4.6 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) represents the quantity of oxygen that corresponds to the total organic substances capable of undergoing degradation through chemical processes. COD serves as an indicator of pollutants present in both water and wastewater. The COD values for effluents from the sugar and dairy industries were found to be quite similar. Specifically, the average COD value for the sugar industry was 46.67 (mg/L), while the dairy industry effluent had an average COD of 51.69 (mg/L). The relative standard deviation (RSD) for COD in the sugar and dairy industry effluents was 14.4% and 18.6%, respectively, indicating some variation in monthly COD data, although not to a significant degree. In summary, the COD results for both industry effluents comply with the Indian standard, "CPCB-General Standards for Discharge-Inland Surface Water," which sets a limit of 250 (mg/L) or less for COD. Consequently, both industry effluents are suitable for irrigation, discharge into inland surface water, as well as use in aquaculture and fisheries.

4.7 Biological Oxygen Demand (BOD)

Biological oxygen demand (BOD) represents the amount of oxygen utilized by microorganisms in breaking down organic matter. Monitoring the BOD of discharged water is crucial because elevated oxygen demand can deplete oxygen levels in water bodies, potentially leading to the death of aquatic organisms. The BOD values for effluents from the sugar and dairy industries are nearly identical. Specifically, the relative standard deviation (RSD) for BOD in sugar and dairy industry effluents is 11.22% and 16.86%, respectively, indicating some variability in monthly BOD data but not to a significant extent. In summary, the BOD results for both industry effluents meet the Indian standard outlined in "CPCB-General Standards for Discharge-Inland Surface Water," which mandates BOD levels of 30 (mg/L) or less. Consequently, both industry effluents are suitable for purposes such as irrigation, discharge into inland surface water, as well as use in aquaculture and fisheries.

4.8 Statistical Evaluation of Physico-chemical Properties

Comparison of mean and RSD values of all the physico-chemical parameters of sugar and dairy industry to evaluate the trend and difference between obtained results.

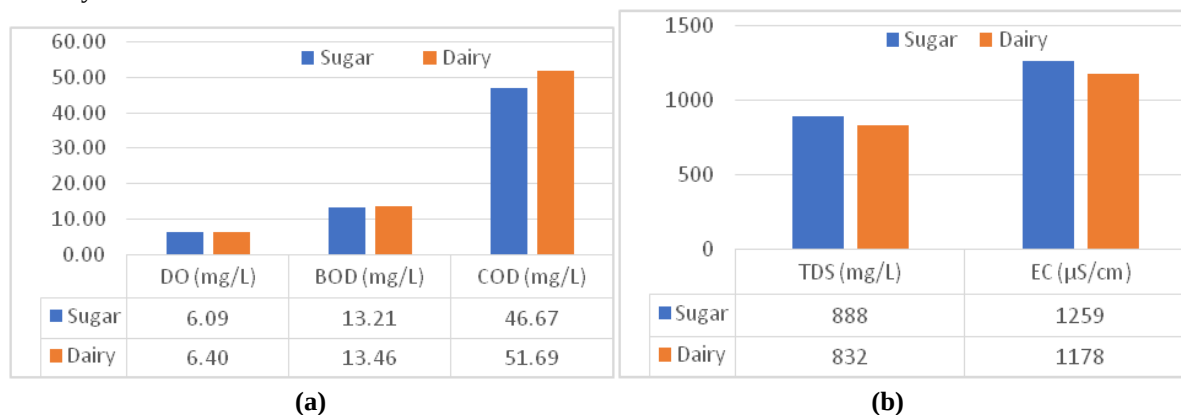


Fig 6 (a & b): Mean of DO, BOD & COD parameters of Dairy and Sugar Industry effluent

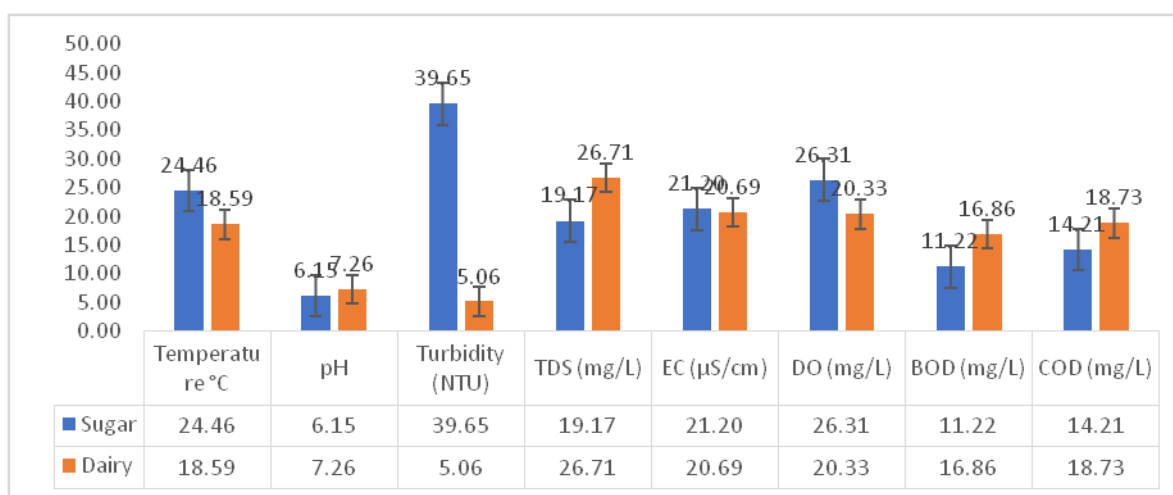


Fig 7: RSD of all Physico-chemical parameters of Dairy and Sugar Industry effluent

The average values for all parameters were found to be nearly identical in both the sugar industry and dairy industry effluents.

High variations in terms of RSD were noticed, particularly for turbidity, TDS, EC, and DO among all the parameters for both industrial effluents.

Since all the physico-chemical parameters fall within the specified Indian standard for discharge into the environment, there is no substantial impact on the ultimate outcome in terms of posing a challenge to the environment.

4.9 Heavy Metals

Trace elements or micronutrients can pose a threat to humans, aquatic organisms, and the environment due to their potential toxicity. These heavy metals, including Chromium (Cr), Cadmium (Cd), Mercury (Hg), Lead (Pb), Arsenic (As), and Nickel (Ni), are naturally occurring but are widely dispersed through processes like mining, manufacturing, and energy production. Heavy metals are soluble in water, making them easily absorbable by living organisms. Once heavy metals enter the human food chain, they can accumulate in the body. Exceeding acceptable limits of heavy metals can often result in harmful effects on humans, the environment, and other living beings. Wastewater contaminated with heavy metals can have a detrimental impact on the environment, humans, and the ecosystem.

Heavy metals typically exhibit a density exceeding 5 grams per cubic centimeter. While there are numerous elements falling into this category, Table-4 highlights those that are particularly relevant in environmental studies. Despite being classified as a semi-metal, arsenic is generally considered a harmful heavy metal. Heavy metals are a significant source of severe health implications. Exposure to substances like mercury and lead can trigger autoimmune responses where an individual's immune system starts attacking its own tissues. Moreover, elevated levels of heavy metals can lead to irreversible brain damage. Consequently, the presence of excessive amounts of these heavy metals in water can pose serious health risks to various living organisms.

Samples containing heavy metals were subjected to analysis using a calibrated ICP-OES instrument. The calibration standards ranged from 0.5 to 10.0 mg/L for all analytes except for arsenic, which had a calibration range of 0.08 to 0.005 mg/L. All heavy metals, excluding arsenic, were analyzed together, while the analysis of arsenic was conducted separately. All calibration curves displayed a high correlation coefficient value exceeding 0.999, illustrated in Figure 8 & Figure 9.

As part of our quality control procedures, negative control samples were processed and acquired alongside test samples and calibration standards illustrated in Figure 9 & Figure 10. The response observed in blank sample was subtracted from test samples. The results obtained from these analyses are presented in Tables 4. It is worth noting that meticulous records of observations and results were maintained in the laboratory during the experiments, in accordance with the principles of Good Laboratory Practices.

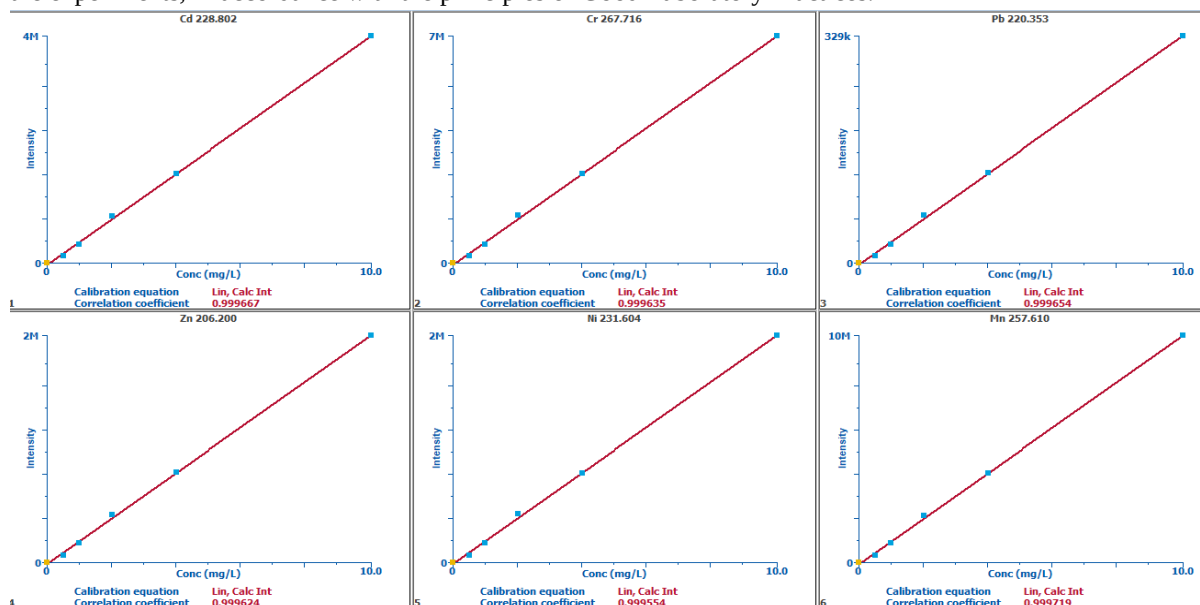


Fig 8: Calibration Curve (Cd, Cr, Ni, Pb, Zn, Fe, Mn)

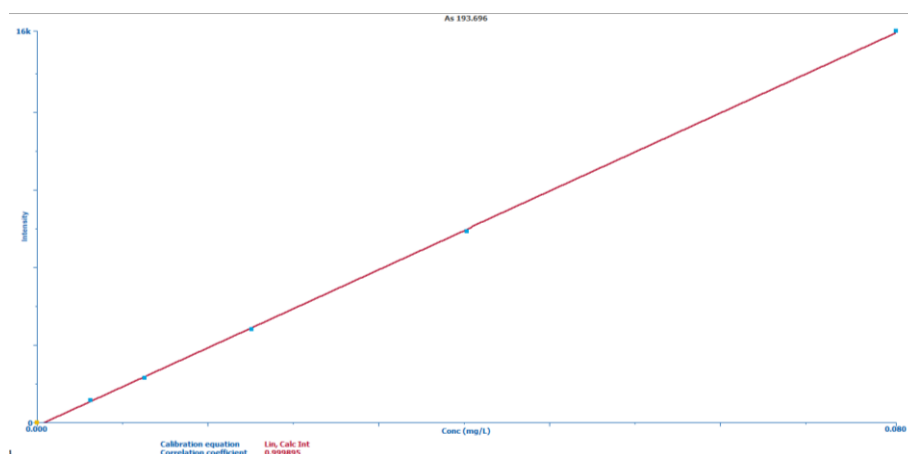


Fig 9: Calibration Curve (As)

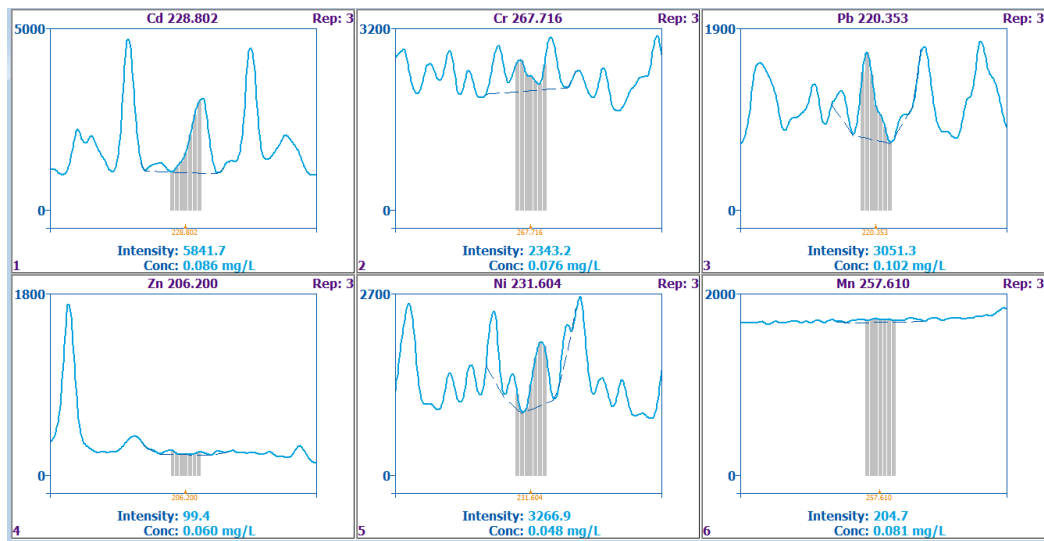


Fig 10: Blank Sample Spectrogram (Cd, Cr, Ni, Pb, Zn, Fe, Mn)

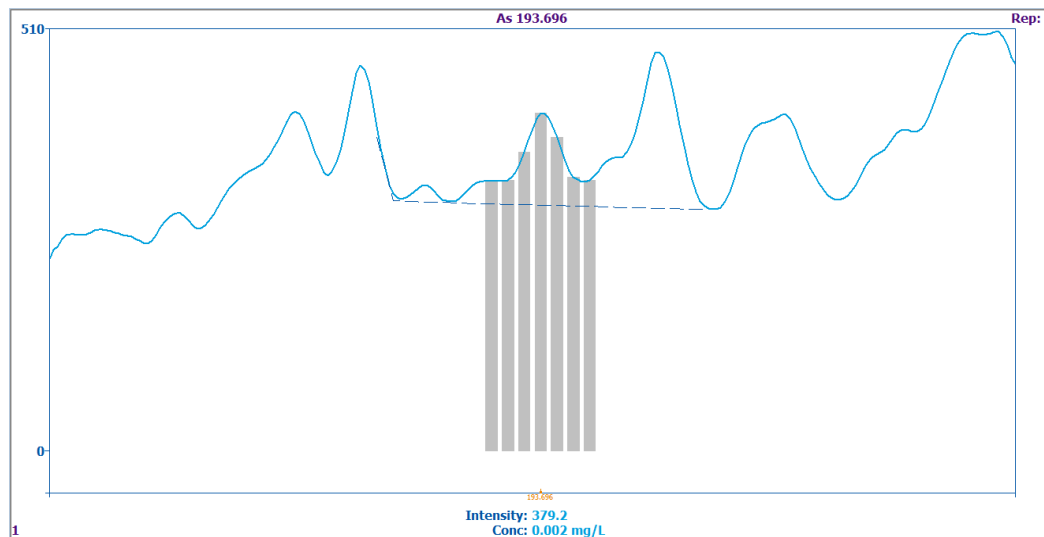


Fig 11: Blank Sample Spectrogram (As)

Table 4: Concentration of Heavy Metals in Treated Effluent of Sugar and Dairy Industries.

Heavy Metal	Dairy Effluent Conc. (mg/L)	Sugar Effluent Conc. (mg/L)	CPCB General Standards (Discharge-Inland Surface Water) (mg/L)	FAO-1985 Water Quality for Agriculture (mg/L)	US EPA-2012, water quality criteria for irrigation (mg/L)
Cadmium	Nil	Nil	2.0	0.01	0.01
Chromium	Nil	Nil	2.0	0.1	0.1
Nickel	0.524	Nil	3.0	0.2	0.2
Lead	1.29	Nil	0.1	5.0	5.0
Zinc	1.66	0.459	5.0	2.0	2.0
Iron	1.36	0.463	3.0	5.0	5.0
Manganese	8.17	3.93	2.0	0.2	0.2
Arsenic	Nil	Nil	0.2	0.1	0.1

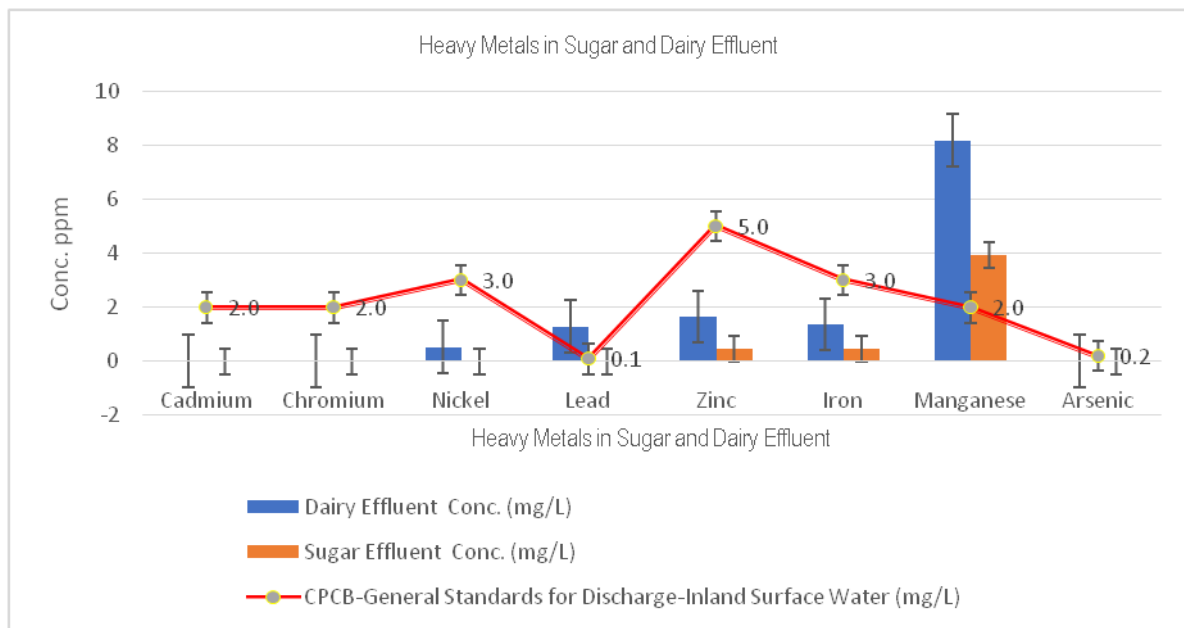


Fig 12: Heavy Metals in Dairy and Sugar Industry effluent

With reference to Figure-12, all heavy metals except lead (Pb) and manganese (Mn) fall within the acceptable limits for both industrial effluent when compared to the Indian standard "CPCB-General Standards for Discharge-Inland Surface Water." The results indicate that lead (Pb) was detected at 1.29 (mg/L) in dairy effluent, exceeding the permissible limit of 0.1 (mg/L) according to the Indian standard. However, there was no lead (Pb) contamination found in sugar effluent.

Manganese (Mn) was identified in dairy and sugar industry effluents at levels of 8.17 (mg/L) and 3.93 (mg/L), respectively, surpassing the Indian standard limit of 2 (mg/L). In the case of lead (Pb) contamination in dairy effluent, when compared to the FAO and USEPA standards, which are relevant for agricultural and irrigation purposes, it was found to be within the permissible limit of 5 (mg/L). Hence, it is considered suitable for use in agriculture and irrigation based on these standards.

Impact on crops: Lead can hinder plant cell growth significantly, particularly when present in very high concentrations. Strict restrictions are imposed on lead (Pb) within the food chain because when it dissolves in water or soil, it can accumulate in crops, posing a risk to human health.

Manganese, on the other hand, can be toxic to several crops, typically in acidic soils. However, manganese (Mn) plays a crucial role in the food chain and plant metabolism. Excessive levels of manganese can disrupt soil structure. Elevated levels of iron, manganese, and sulfides in combination with acidic conditions can interfere with the nutrient absorption process in paddy rice.

While it is advisable for discharged effluents to adhere to the permissible limits set by Indian standards, industries should also be encouraged to have remedial plans in place for addressing such occurrences. Additionally, there are available methods and procedures for removing these heavy metals from wastewater.

4.10 Heavy metal evaluation index (HEI)

Effluent quality in terms of heavy metals can be computed (table-5 & table-6) by using HEI method given by Edet and Oiong, Chanchal Verma [24, 25] as: $HEI = \sum_{i=1}^n H_c / H_{mac}$

Where H_c is the experimental value of heavy metal and H_{mac} the maximum allowable limit of that heavy metal.

Table 5: Heavy Metal Evaluation Index for Dairy Industry effluent against CPCB standards.

	Dairy Effluent Conc. (mg/L)	CPCB General Standards Discharge- Inland Surface Water		

		(mg/L)		
Heavy Metal	Hc	Hmac	Hc/ Hmac	HEI
Cadmium	Nil	2.0	0.0	17.9
Chromium	Nil	2.0	0.0	
Nickel	0.524	3.0	0.2	
Lead	1.29	0.1	12.9	
Zinc	1.66	5.0	0.3	
Iron	1.36	3.0	0.5	
Manganese	8.17	2.0	4.1	
Arsenic	Nil	0.2	0.0	

Table 6: Heavy Metal Evaluation Index for Sugar Industry effluent against CPCB standards.

	Sugar Effluent Conc. (mg/L)	CPCB-General Standards for Discharge-Inland Surface Water(mg/L)		
Heavy Metal	Hc	Hmac	Hc/ Hmac	HEI
Cadmium	Nil	2.0	0.0	2.3
Chromium	Nil	2.0	0.0	
Nickel	Nil	3.0	0.0	
Lead	Nil	0.1	0.0	
Zinc	0.459	5.0	0.1	
Iron	0.463	3.0	0.2	
Manganese	3.93	2.0	2.0	
Arsenic	Nil	0.2	0.0	

The Heavy Metal Evaluation Index (HEI) offers a more comprehensive understanding of heavy metal contamination. Edet and Offiong (2002) have provided the following categorization for projected HEI values: HEI < 10 is considered low, HEI = 10-20 falls in the medium range, and HEI > 20 is classified as high. The computed HEI values indicate that, when compared to the CPCB (Indian) standards outlined in Table-5, the effluent quality for dairy effluent falls within the medium range of metal contamination. In the case of sugar industry effluent, it falls within the low range of metal pollution when assessed against the CPCB (Indian) standards presented in Table-6.

4. Conclusion

The sugarcane effluent exhibited a clear appearance, whereas the dairy effluent displayed a creamy white hue. The findings indicate that the physicochemical characteristics of effluents from both the sugar and dairy industries fell within the permissible limits for reuse in agricultural irrigation or discharge into inland surface water for aquaculture.

In terms of heavy metal contamination, there were no detectable levels of Cadmium (Cd) or Chromium (Cr) in either the sugar or dairy industry discharge water. Nickel (Ni) was absent in the sugar industry effluent but registered at 0.524 mg/L in the dairy industry effluent. Lead (Pb) was not found in the sugar industry discharge but was present at 1.29 mg/L in the dairy industry discharge. Zinc (Zn) levels were 0.459 mg/L in the sugar industry and 1.66 mg/L in the dairy industry effluent. Iron (Fe) concentrations were 0.463 mg/L in the sugar industry and 1.36 mg/L in the dairy industry effluent. Manganese (Mn) levels were 3.93 mg/L in the sugar industry and 8.17 mg/L in the dairy industry effluent, while Arsenic (As) was not detected in either effluent.

All other parameters, except for heavy metals, did not exhibit a consistent pattern; instead, they displayed fluctuations with a significant RSD. The presence of heavy metal contaminants in the treated water

may be attributed to leaching out during the production process or the accumulation of specific heavy metals, notably toxic lead (Pb) and manganese (Mn), within the production system.

Nevertheless, with the exception of a few heavy metals like lead (Pb) and manganese (Mn), all other parameters fell within the permissible limits outlined by the CPCB General Standards for Discharge in Surface Water and Land for agricultural purposes. These findings from the study strongly indicate that if effluents are not adequately treated before being released into the environment, they could potentially have adverse effects on both aquatic and terrestrial ecosystems. Therefore, we strongly advocate for the implementation of effective methods for removing heavy metals in wastewater treatment.

Furthermore, we recommend that the concentrations of heavy metals in discharged effluents from both the sugar and dairy industries should comply with CPCB standards. These concentrations should be assessed before discharge into the environment, even if the effluent is intended for irrigation or agricultural use, in accordance with the recommended limits set by FAO and USEPA for heavy metals.

In terms of Heavy Metal Equivalent Index (HEI) values, it's noteworthy that the dairy industry effluent contains a higher load of heavy metals compared to the effluent from the sugar industry.

The outcomes of this study provide valuable insights into the quality of wastewater discharged by the dairy and sugar industries. Proper management of treatment plants can help maintain or even enhance the quality of wastewater within safe limits. While the physico-chemical contaminants in both dairy and sugar industry treated wastewater generally meet permissible standards, the sugar industry effluent exhibits elevated levels of lead and manganese contamination, whereas the dairy industry effluent primarily contains manganese contamination in the discharged wastewater.

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References

- [1] Liu J, Liu Q, Yang H. (2016). Assessing water scarcity by simultaneously considering environmental flow requirements, water quantity, and water quality. *Ecological indicators* 2016, 60:434-441.
- [2] Liu J, Yang H, Gosling SN, Kumm M, Flörke M, Pfister S, Hanasaki N, Wada Y, Zhang X, Zheng C. (2017). Water scarcity assessments in the past, present, and future. *Earth's future*, 5(6):545-559.
- [3] Maxmen A: As Cape Town water crisis deepens, scientists prepare for Day Zero'. *Nature* 2018, 554:13-14.
- [4] Mann M.E., Gleick P.H. (2015). Climate change and California drought in the 21st century. *Proceedings of the National Academy of Sciences*, 112(13):3858-3859.
- [5] Kaur V., Sharma G. (2017). "Impact of Dairy Industrial Effluent of Punjab (India) on Seed Germination and Early Growth of Triticum Aestivum." *Indian Journal of Science and Technology* 10(16): 1-9.

- [6] Verma A., Singh A. (2017). "Physico-Chemical Analysis of Dairy Industrial Effluent." *International Journal of Current Microbiology and Applied Sciences* 6(7): 1769–75.
- [7] A.S. Kolhe, S. R. Ingale, and R.V.Bhole. (2008). "Effluent of Dairy Technology." *International Research Journal of Sodh, Samiksha & Mulyankan* 4(1): 303–6.
- [8] Bell S: Urban water systems in transition. *Emergence: Complexity and Organization* 2012, 14(1):45.
- [9] Furumai H: Rainwater and reclaimed wastewater for sustainable urban water use. *Physics and Chemistry of the Earth, Parts A/B/C* 2008, 33(5):340-346.
- [10] New W: WATER REUSE. *The Water Wheel* 2017:36.
- [11] US Environmental Protection Agency. (2019). "Guidelines for Water Reuse."
- [12] Ogoshi M., Suzuki Y., Asano T. (2001). Water reuse in Japan. *Water Science and Technology*, 43(10):17-23.
- [13] US Environmental Protection Agency. (2012). "Guidelines for Water Reuse." *Development* 26(September): 252. <http://www.epa.gov/nrmrl/pubs/625r04108/625r04108.pdf>.
- [14] APHA, Standard Methods for the Examination of Water and Wastewater. APHA, AWWA and WEF, 24th Edition, 2023.
- [15] APHA, AWWA, WEF. (1998), Standard Methods for the Examination of Water and Wastewater, 20th Edition.
- [16] Trivedy R.K. and Goel P.K. (1998). "Chemical and Biological Methods for Water Pollution Studies," Environmental Publications, Karad.
- [17] CPCB General Standards, Sawal, M. (1986). "General Standards for Discharge of Environmental Pollutants." *The Environment (Protection) Rules* 2(174): 545–60.
- [18] CPCB Dairy Industry Discharged Effluent: The Environment (Protection) Rules, 1986 for Dairy effluent discharge in environment as disposal on land and disposal in surface water.
- [19] CPCB Sugar Industry Discharged Effluent: The Environment (Protection) Rules, 1986, Amendment rule 2016, for Sugar industry effluent discharge in environment as disposal on land and disposal in surface water.
- [20] CPCB General Standards for Discharge: CPCB adopted The Environment (Protection) Rules, 1986, SCHEDULE – VI, GENERAL STANDARDS FOR DISCHARGE OF ENVIRONMENTAL POLLUTANTS PART-A: EFFLUENTS.
- [21] Food and Agriculture Organization, 1985 (FAO): Standard for Water Quality for Agriculture, given by United Nation & WHO (R.S. Ayers and D.W. Westcot).
- [22] IS 2296:1992: CPCB, Water Quality Standards in India; Designated Best Uses of Water.
- [23] Anna F Rusydi., 2018, Research Center for Geotechnology, LIPI, Bandung, Indonesia
- [24] Edet AE, Oiong OE (2002) Evaluation of water quality pollution indices for heavy metal contamination monitoring: a study case from Akpabuyo-Odukpani area, lower cross river basin (South Eastern Nigeria). *Geo J* 57:295–304
- [25] Chanchal Verma, Athar Hussain, Sangeeta Madan, Viет Kumar (2021), Assessment of heavy metal pollution in groundwater with respect to distance from ash pond by using heavy metal evaluation index, *Applied Water Science* (2021) 11:58